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# A practical chronology for the abalone *Haliotis fulgens*

S. A. Shepherd
South Australian Research and Development Institute,
P.O. Box 120 Henley Beach 5022 South Australia
and
J. R. Turrubiates-Morales
Instituto Nacional de Pesca, Crip-la paz,
Km 1 carr. Pichilingua, La Paz, bcs Mexico

*"The smallest spiral holds the history*
*Of something tiny in the battering sea"*
The Seashell, Judith Wright

Abstract

The abalone *Haliotis fulgens* deposits fine (non-pigmented) and dark (pigmented) rings in the spire that are useful for aging the shell. A dark ring is deposited annually, and in the first 4–5 years is preceded by one or more fine rings which are deposited with decreasing frequency over time. External shell erosion causes the loss of about one ring per 32 mm shell length over about 80 mm length. The El Niño events of 1982–3 and 1991–2 caused growth checks in shells of *H. fulgens* at La Natividad and Bahia Tortugas, Baja California and were used as a time-stamp to validate the rate of deposition of dark rings in the shell. In about 9% of the shells examined more or less dark rings are deposited than expected. In these cases counts of fine rings as well as dark rings can reduce the chance of error.

*Keywords: Haliotis fulgens*; rings; chronology; shell-aging; El Niño.

## Introduction

The ability to age abalone shells is a valuable tool for management of their fisheries. Validation of the technique has been problematic but has advanced with ultrastructural studies (Erasmus *et al.* 1994; Shepherd *et al.* 1995a) and the use of time-stamps such as natural growth-checks or artificial fluorochromes (Shepherd *et al.* 1995b; Day *et al.*1995).

After the discovery of rings in the spire of abalone shells by Hayashi (1955), Muñoz-Lopez (1976) proposed their use in aging shells of *Haliotis fulgens* Philippi which deposits non-pigmented rings (called fine rings) and pigmented rings (called dark rings). However he neither specified the type of ring he counted nor did he validate the method. Shepherd *et al.* (1995a) showed that *H. fulgens* deposits on average 4 rings in the first year and 3 rings in each of the next 3 years but they likewise did not distinguish the two types of ring and they only examined the rate of deposition of rings during the first 4–5 years of age. Turrubiates and Castro (1992) counted only the dark rings to age the shell, assuming a rate of one a year, and found fair agreement between growth rates estimated from mark-recapture studies and those from shell-aging. In this paper we evaluate Turrubiates and Castro's (1992) method. We re-examined the same shells aged by Turrubiates and Castro, as well as other samples, and describe the pattern of deposition of fine and dark rings.

The El Niño oceanographic events of 1982–3 and 1991–2 were both strong episodes which elevated sea temperatures by 2–3°C in Baja California and eliminated for a year the giant kelp *Macrocystis pyrifera* from the region. These events are known to cause prominent growth checks in abalone shells (Cox 1962) and they did so in abalone shells in this region (Shepherd and Avalos-Borja 1997). We estimated the date of deposition of "EL Niño" growth-checks in 1983 and 1991 in *H. fulgens* and used them as time-stamps to determine the rate of deposition of dark rings, and so confirm the validity of Turrubiates and Castro's aging technique.

## Methods and materials

We examined a sample of 75 shells taken from Bahia Tortugas (27°40' N; 114°52' W) in October 1984, first studied by Turrubiates and Castro (1992), and a second sample of 72 shells taken commercially from La Natividad (27°51'26" N; 115°7'30" W) in March 1995. The spires of the shells were ground down with an electric grinder and polished with 200–600 grit abrasives until a minute hole appeared (termed a horizontal section) as described by Shepherd *et al.* (1995a). The rings exposed by this section were counted from the outer margin to the central hole, and recorded as: $f_1$, $d_1$; $f_2$, $d_2$; ....$f_n$, $d_n$ where $f_n$ is the number of fine rings immediately preceding the nth dark ring $d_n$. Shells showing aberrant patterns e.g. long (6–8) initial sequences of fine or dark rings were excluded from the analysis.

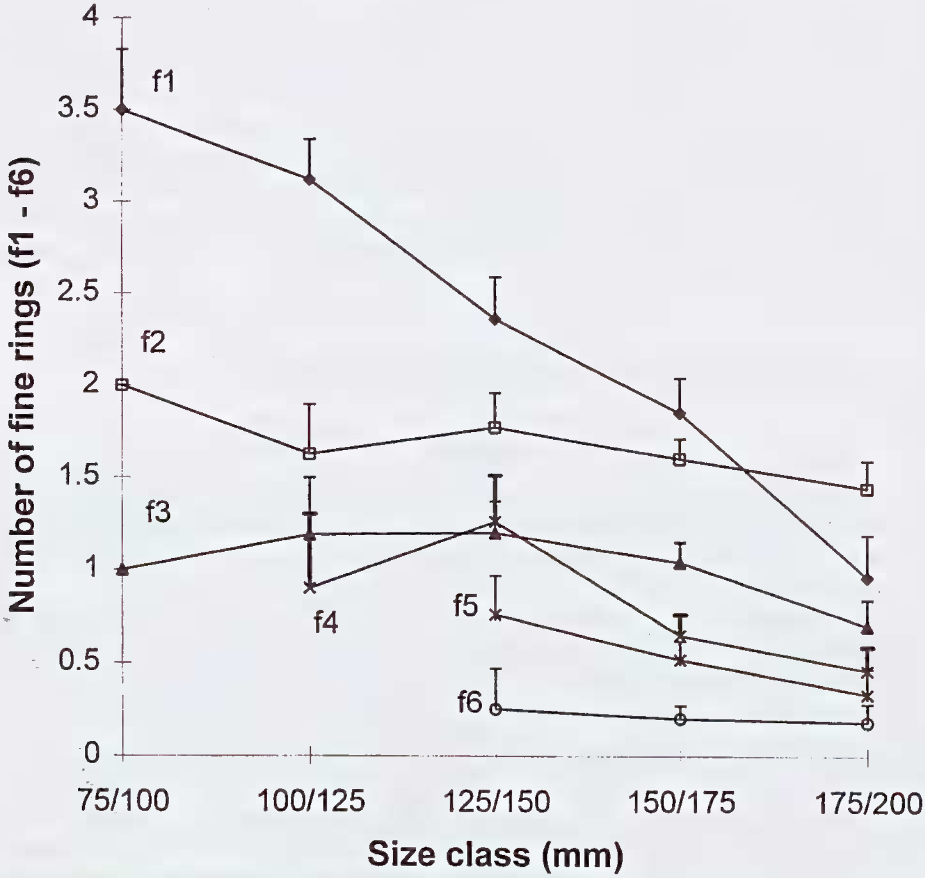


Figure 1. Plot of mean number of fine rings, $f_1$-$f_6$, preceding the dark rings, $d_1$ to $d_6$ for five different size classes of shell length. Vertical bars are standard errors. Sample sizes are: $f_1$, n=143; $f_2$, n=146; $f_3$, n=150; $f_4$, n=133; $f_5$, n=111; $f_6$, n=72.

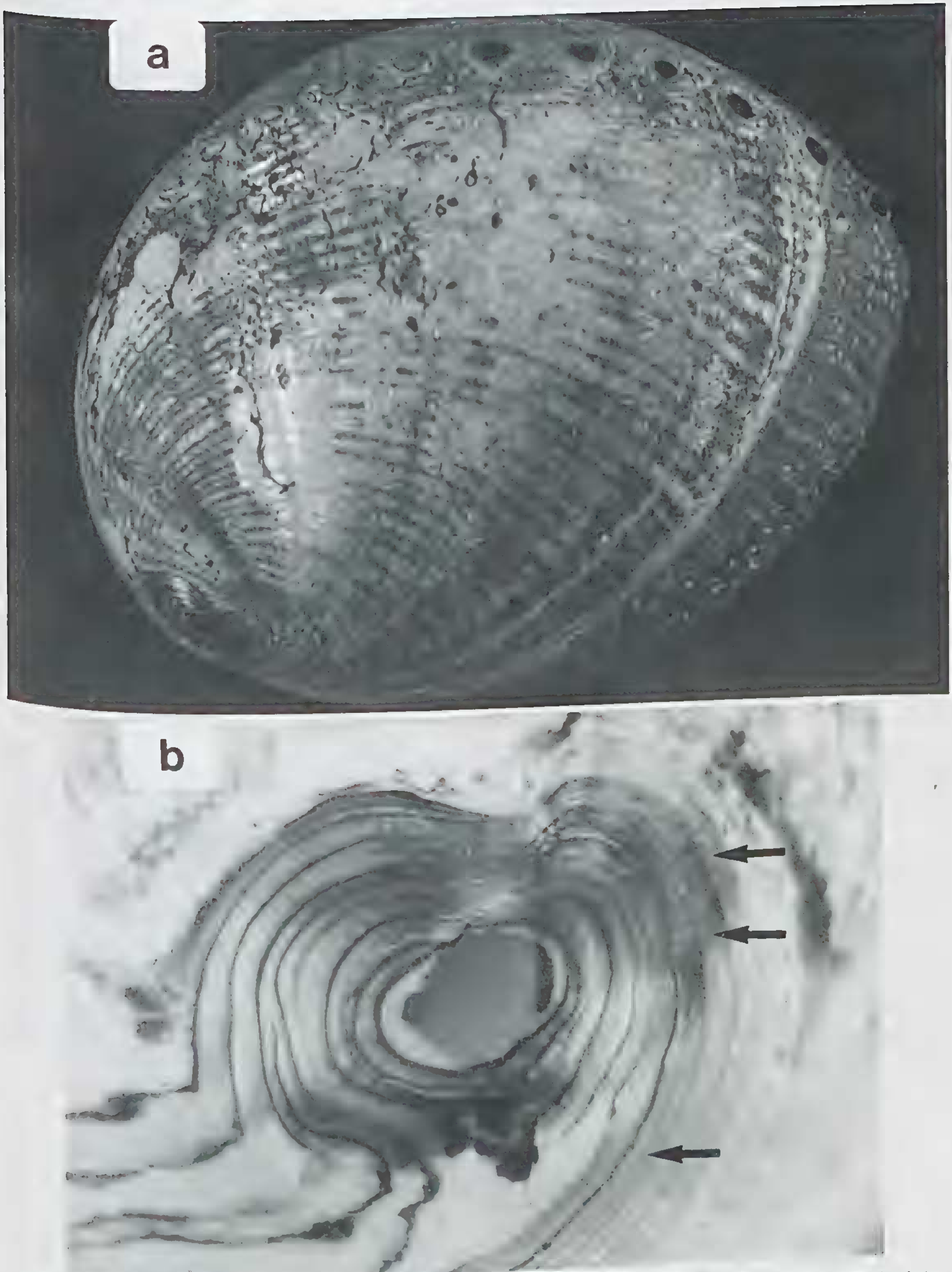


Figure 2. **a**. Photograph of shell (159 mm SL) of *H. fulgens* from La Natividad showing an "El Niño" growth check (see arrowhead) at $SL_1$=137 mm. **b**. Photograph of horizontal section of the same shell showing sequence of dark rings with 1–3 fine rings (indicated by arrows) between the outer dark rings.

From the above samples we selected shells showing a prominent growth check and measured shell length to the growth check ($SL_1$) and total shell length (SL) in mm and counted the number of dark rings. To estimate the date of deposition of the growth check we selected a subset of the shells where $100mm<SL<148$ mm. Although the aging technique of Shepherd *et al.* (1995a) has been strictly validated only to 130 mm SL the data suggested validation could be safely extrapolated for another year to 148 mm SL. That technique counts fine and dark rings and then applies an equation relating age and number of rings after taking into account loss of rings through shell erosion. We assumed a uniform birthdate on 1 November in accordance with the known time of spawning (Ortiz *et al.* 1990), and estimated the year of birth of each shell. Assuming a linear growth rate of 32 mm per year to 128 mm SL and 20 mm in the 5th year (Shepherd *et al.* 1995a) we obtained, by interpolation, an estimate of the age ($A_1$) when the growth check ($SL_1$) was laid down, and hence the date of deposition. We then estimated the age of shells >148 mm SL with "El Niño" growth checks by a two step procedure i.e. by first estimating the age to $SL_1$ as described, and then by adding the time period from the mean date of deposition of the growth check to the date of capture of the shell. For each site the number of dark rings was plotted against the estimated age of each shell, and the data analysed by least squares regression.

Growth rates were examined by two independent methods at each site. First, the El Niño growth check data were used to estimate von Bertalanffy growth parameters by plotting the increment ($SL-SL_1$) vs mean length ($(SL_1+SL)/2$) which is the Gulland- Holt plot (Gulland 1983). Second, the age-length data obtained from aged shells were analysed by Ford- Walford plots (Gulland 1983). These simple analyses were used for comparison with published growth parameters derived by the same methods at the same sites. The length-increment data for Bahia Tortugas also included data from three tagged shells recaptured 1–3 years after marking.

## Results

### Rings

A plot of the mean number of fine rings preceding the first 6 dark rings vs shell length (grouped for ease of presentation in 4 size classes) (Fig.1) shows that a mean of 3.5 rings (range 2–6) are initially laid down before the dark ring $d_1$, about two before $d_2$, one before $d_3$ and $d_4$, and thereafter fine rings are seldom deposited. A regression of $f_1$ (the number of fine rings preceding the first dark ring) vs shell length gave the equation: $f_1 = 5.0 - 0.020$ SL ($r^2 = 0.42$) (n=118) indicating an average loss of one ring per 32 mm over the length range 75–200 mm SL. None of the slopes of the regressions of $f_2, f_3, \ldots f_6$ vs shell length were significant (in each case $t< 1.5$ n.s.). In 7% of the shells we observed a sequence of up to 8 fine rings before a dark ring indicating that no dark rings were laid down in the first 2 years. Conversely in 2% of the shells we observed a sequence of dark but no fine rings indicating that in the first 2–3 years scarcely any fine rings were laid down. A typical shell with sequences of fine and dark rings is shown in Figure 2b. Many of the shells taken in October or November samples showed partial or very recent deposition of a dark ring suggesting that the dark ring is deposited around spawning time.

Table 1. Parameters of regression equations of observed number of rings (R) vs predicted age (A) in years. The equation is of the form R = a + b A

| | a | b | s.e | $r^2$ | N |
|---|---|---|---|---|---|
| La Natividad | –0.33 | 1.05 | 0.06 | 0.90 | 47 |
| Bahia Tortugas | –0.39 | 1.08 | 0.05 | 0.98 | 22 |

## Growth checks

An example of an "El Niño" growth check is shown in Figure 2a. For the 1995 sample from La Natividad 16 shells 135–148 mm SL showed a prominent growth check. The mean date of deposition of the check was on 18 November 1991 (s.e.10 days). For the sample from Bahia Tortugas there were 11 such shells 102–148 mm SL. The mean date of deposition of the growth check was on 4 October 1983 (s.e. 9 days). Samples of shells (N=47) from La Natividad taken from 1989–1991 showed no such growth checks. Plots of the observed number of dark rings vs the estimated age are given in Figure 3 and the parameters of the fitted regression equations are given in Table 1. The mean period "at liberty" i.e. from the date of the growth check to the date of capture was 3.3 years at La Natividad; for the Bahia Tortugas sample the period was one year for 15 shells captured in October 1984 and 7 years for 5 shells captured in November 1990. In both cases the 95% confidence interval of the regression slopes include unity indicating that on average one dark ring is deposited annually.

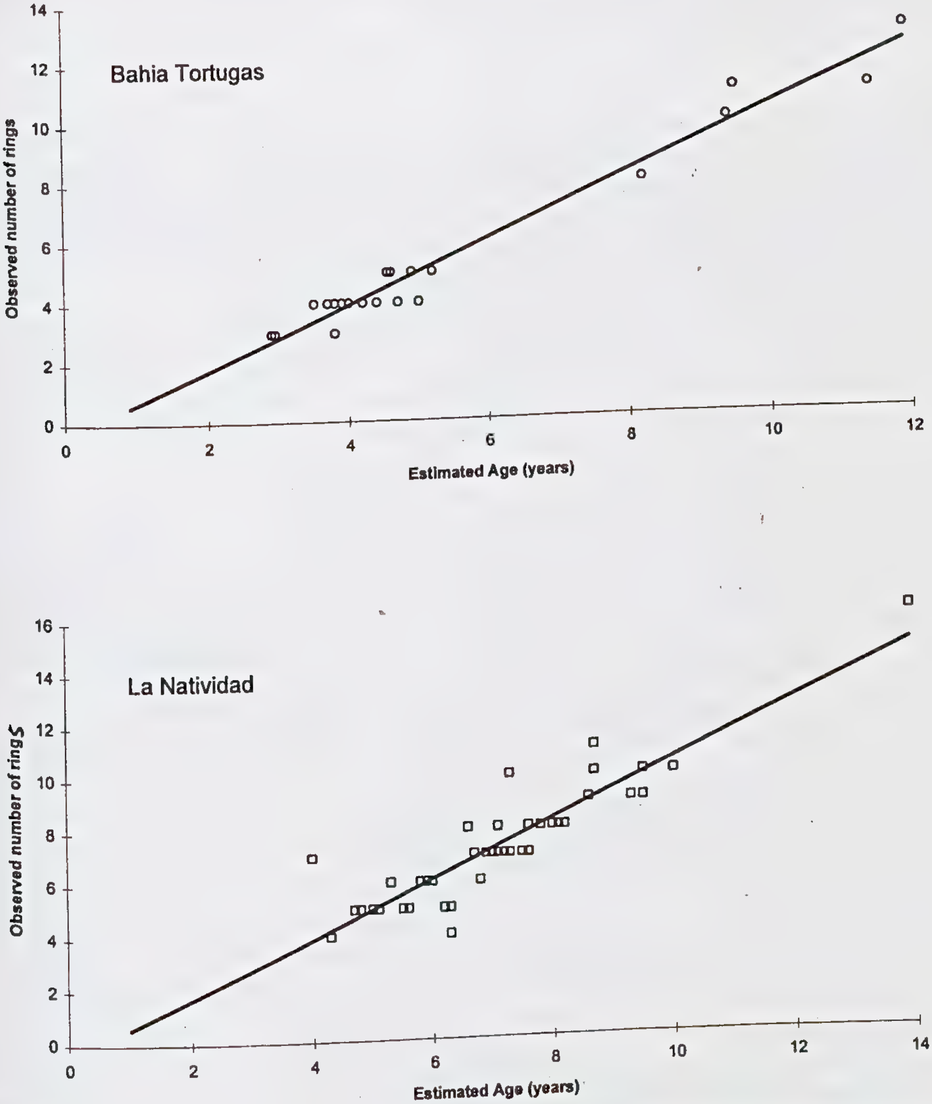


Figure 3. Plots of observed number of dark rings vs estimated age (yrs) at La Natividad and Bahia Tortugas.

Table 2. Comparison of parameters of von Bertalanffy growth model fitted to length-increment (L-I) and age-length (A-L) data for *H. fulgens* at (1) Bahia Tortugas and (2) La Natividad in this paper and previously published work.

| Site | Date | N | $t_o$ (s.e) | K(s.e) | $L_\infty$ (s.e) |
|---|---|---|---|---|---|
| (1) | L-I (this paper) | 24 | n.a. | 0.37 (0.04) | 190.2 (5.9) |
| (1) | L-I (Shepherd et al. 1991) | 32 | n.a. | 0.38 (0.04) | 183.1 (6.1) |
| (1) | L-I (Turrubiates and Castro 1992) | 38 | n.a. | 0.44 | 177* |
| (1) | A-L (this paper) | 65 | 0.36 (0.16) | 0.36 (0.06) | 182.6 (8.5) |
| (1) | A-L (Turrubiates and Castro 1992) | 453 | 0.43 | 0.24 | 175.3 |
| (2) | L-I (this paper) | 49 | n.a. | 0.35 (0.02) | 187.1 (3.1) |
| (2) | A-L (this paper) | 159** | 0.78 (0.41) | 0.29 (0.07) | 179.6 (7.0) |

* Turrubiates and Castro (1992) fixed $L_\infty$ at 177 mm and then derived K.

** includes a 1985 sample from La Natividad

### Growth rates

Growth parameters derived from length-increment data (El Niño growth checks) and age-length data are given in Table 2 and compared with published values mostly analysed in the same way. The growth parameters for Bahia Tortugas are very close (with overlapping standard errors) to those published by Shepherd *et al.*(1991) but higher than those of Turrubiates and Castro (1992) for age-length data. There are no previously published growth parameters for La Natividad but the two methods produce parameters whose standard errors also overlap.

To test the effect of loss of rings from shell erosion on our estimates of the growth parameters we took an extreme case and assumed that every shell >175 mm SL had lost one dark ring, i.e. that age was under-estimated by one year, and then recalculated the growth parameters for the age length data. The parameters were lower by between 0.3–1.2% and in no case significantly so. So we concluded that shell erosion causes no significant bias to estimates of growth parameters.

## Discussion

This study confirms some of the findings of Shepherd *et al.* (1995a), gives additional information on the dynamics of fine ring deposition, and most importantly validates Turrubiates and Castro's (1992) method of aging this abalone over its full size range. The average number of rings deposited in the first year (3.5) is slightly less than that (3.9) which Shepherd *et al.*(1995a) found, but the variability is higher than was formerly thought. The change in pattern of fine rings with age means that the technique of Shepherd *et al.* (1995a), while useful for about the first 4–5 years, is not valid for older shells. In such shells counts of the dark rings are the only reliable indicator of age. However, we recommend using both techniques in shells to about 5 years old because of the variability in pigmentation of rings. We also advocate the use of horizontal sections which show the pigmentation more clearly but note that fine rings are sometimes missed in horizontal section although visible in vertical section (Shepherd *et al.* 1995a). So far the only other species of abalone which shows an alternating pattern of fine and dark rings is *H. iris* (unpublished observations). The mean erosion rate of rings (1 ring per 32 mm SL) is very close to that (1 ring per 32.3 mm SL) found by Shepherd *et al.*(1995a) but may be under-estimated for very large shells. The largest size class of shells examined (175–200 mm SL) would on average have lost 3.5 rings which is the mean number of fine rings before the first dark one. So some must have lost the first dark ring as well. In these cases second year rings would have been counted as first year rings so leading to an under-estimate of age. However, this bias seems not to be serious, at least for estimating growth rates, as it had no significant effect on our estimates. The 1982–3 and 1991–2 El Niño events were both intense and persisted for over a year. The event was stronger in the fall of 1983 than of 1982 (Dayton and Tegner

1984; Norton *et al.* 1985), but conversely was stronger in 1991 than in 1992 (Haywood *et al.* 1994). This may explain why growth checks occurred in shells in late 1983, but not in 1982 and in late 1991 but not in 1992. While large temperature changes and loss of algae are of likely importance in producing a growth check (see Shepherd *et al.* 1995b), spawning may also be a factor.

### Growth rates

The closeness of our parameter estimates for the growth check data to other published values (Table 2) reinforces the conclusion that the growth checks were laid down consistently at about the same time during the El Niño events.

The discrepancies between growth parameters derived for length-increment data and age-length data are not surprising given that the analyses address different questions (Francis 1988; and see discussion in Day and Fleming 1992). The discrepancy between our parameter estimates and those of Turrubiates and Castro (1992) for the age-length data at Bahia Tortugas (Table 2), (our data being a subset of those of Turrubiates and Castro), may be due to differences in the estimated ages of younger shells. In this study our estimates were better because we counter-checked the age by counting fine rings and so could detect aberrations in the number of dark rings deposited (see Results).

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